Nutrient Fluxes for Two Small Forested Watersheds: Sixteen-year Results from the West Virginia University Forest

James S. Rentch and Ray R. Hicks, Jr.

Bulletin 724
West Virginia
Agricultural and Forestry
Experiment Station

Nutrient fluxes for two small forested watersheds: sixteen-year results from the West Virginia University Forest

James S. Rentch and Ray R. Hicks, Jr.

Table of Contents

Introduction

The cycling of mineral nutrients is one of the most important processes occurring in forest ecosystems, and temperate deciduous forests are remarkably conservative and efficient systems. Plants take up nutrients during the growing season, utilize them in plant processes such as photosynthesis, and metabolize them into a variety of forms of biomass. Some nutrients are sequestered into wood and root tissue, but much of the annual nutrient uptake is returned to the system as leaf detritus and woody debris, where decomposition eventually releases it in forms that are again available for uptake by plant roots. Nutrient cycling is therefore a pattern of fluxes in the system: the processes of uptake, use, and reuse over time. It is a seasonally regulated process driven by phenological variations in biotic processes such as tree growth and dormancy that are themselves regulated by cyclical climatic processes such as temperature, precipitation, and solar radiation (Hicks et al. 1992). Because of intra-system nutrient cycling and the retention of past inputs, plant growth is not solely dependent on external inputs to the system. In fact, the annual recirculation of essential elements such as nitrogen (N), calcium (Ca), phosphorous (P), and potassium (K), from detritus alone is sufficient to exceed the growth requirements of a northern hardwood forest (Schesinger 1997). Nutrient budgets are the accounting system that balance inputs to the system against outputs over a given time scale. Because they express the cycling process in terms of periodic net gain or loss, nutrient budgets provide one measure of ecosystem health and sustainability.

An accurate accounting of inputs and outputs to an ecological system is important for several reasons. First, ecosystem productivity is strongly dependent on the total pools of nutrient resources present, their availability, their seasonal fluxes, and whether their long-term status is improving, declining, or remaining static. Productivity also depends on a proper balance of nutrients. Plant tissue is composed of a fairly stable mixture of carbohydrates, and macro- and micronutrients, and when one nutrient becomes limiting, plants usually do not show deficiency symptoms; they simply grow more slowly (Schlesinger 1997). Input-output budgets are a key indicators of variations of soil fertility and the potential sustainability of forest management; they permit forest managers to anticipate how management activities will initiate soil changes before the impact on soil and vegetation appear (Ranger et al. 1999).

There is strong evidence that human actions can influence nutrient status of a site at macro-, meso-, and micro-scales. For example at the macro-scale, precipitation in the central Appalachian Region is among the most acidic in the United States, and pH readings below 4.0 are common in summer months. The buffering of acidic precipitation by forested watersheds is a chemical process that occurs as water from precipitation passes through the ecosystem, and some scientists believe that acid precipitation may accelerate nutrient leaching from forest foliage and the soil profile (Helvey and Kunkle 1986). When combined with the micro-scale activity of timber harvesting on short rotations (i.e., 50-60 year), persistently negative budgets may conceivably result in depletion of some essential nutrients, and require remedial efforts to restore site

productivity (Federer et al. 1989, Long et al. 1997). Finally, because conservation of forest resources also includes non-timber values such as water quality and control, biodiversity, wildlife habitat, recreational opportunities, and carbon sequestration, for example, nutrient budgets have the potential for far-ranging effects on a wide variety of ecosystem functions and values.

In this study, we examined nutrient inputs and outputs, and constructed nutrient budgets for two small, forested watersheds in the West Virginia University Forest near Morgantown, West Virginia, for the period 1984-1999. This study extends a previous summary by Hicks et al. (1992), which examined the period 1984-1990. It is patterned after the small watershed studies at the Hubbard Brook Experimental Forest (Likens and Bormann 1995), and like that study, it assumes that parent material beneath the watersheds is relatively impermeable, and thus groundwater losses are negligible. Large, residual pools are held in system soils and parent materials, but for the purposes of this study, release from soils and weathering products are fluxes internal to the system and not considered inputs (Ranger et al. 1999). Nutrient budgets then, may be calculated by a simple subtraction of streamwater outputs from precipitation inputs to derive the net gain or loss of (at least for those nutrients without a prominent gaseous phase). Theoretically then, the difference between annual input and output for a selected chemical constituent tells whether it is being accumulated within the system (inputs > outputs), lost from the system (inputs < outputs), or is quantitatively being passed through the system (inputs = outputs).

This study has three objectives: 1) to update and summarize the most recent ten years of climatological, hydrological, and input/output nutrient concentration data for the two watersheds; 2) to derive a mathematical relationship between stream discharge and climatic variables, so that mass-based nutrient outputs (kg/ha) may be estimated in the absence of actual stream discharge measurements; and 3) to construct nutrient budgets for the two watersheds for several key nutrients.

Study Area

The two small watersheds selected for study are located in the West Virginia University Forest in Preston County, WV. The entire 13,000-acre Coopers Rock State Forest, of which the WVU Forest is a part, has been significantly disturbed during the 250 years since European settlement. In the early 19th century, approximately 250 acres were cut annually for charcoal for iron production. Between 1870-1910, several high-grade cuts were made for specific species, and the entire tract was systematically logged between 1911 and 1939. Only scattered cull trees such as chestnut oak (*Quercus prinus*), scarlet oak (*Q. coccinea*), and black gum (*Nyssa sylvatica*) remained after cutting. Fueled by logging debris, the denuded areas burned almost annually (Carvell 1973). In the aftermath, prolific sprouters such as red maple (*Acer rubrum*), sassafras (*Sassafras albidum*), and blackgum became more abundant than yellow-poplar (*Liriodendron tulipifera*) on many good sites. The Coopers Rock State Forest was purchased by the state of West Virginia in 1936, and in 1959, approximately one-half the forest was

designated as the West Virginia University Forest, to be used for teaching, research, and demonstration purposes.

The two study watersheds lie along perennial tributaries of Little Laurel Run. Watershed 1 (WS1) encompasses a 40-acre site that occurs primarily on a northeast-facing slope, and is dominated by yellow poplar, with components of northern red oak (*Quercus rubra*), black cherry (*Prunus serotina*), and red maple. In the fall of 1997, an improvement cut was made in this tract which removed low grade stock and favored 10-20 in. crop trees, particularly yellow poplar, northern red oak, and black cherry. Watershed 2 (WS2) is a 75-acre tract that is primarily southwest facing, and is dominated by chestnut oak and northern red oak. Forests in both watersheds are approximately 70-year old, even-aged stands, primarily of sprout origin (Hicks and Frank 1984). Of the two watersheds, WS1, on the northeast-facing slope, generally possesses better growing sites. WS1 has generally fewer and larger trees, even though both stands are approximately the same age. Site indices, and stand statistics reflect the different site qualities of the two watersheds. In 1990, quadratic mean diameters for WS1 and WS2 were 10.4 in. and 9.2 in., respectively. WS1 had 203 trees per acre (tpa, dbh >1 in.), a basal area per acre of 134 ft^2, and an oak site index (SI) of 81 (base age 50). Comparable values for WS2 are, 260 tpa, 125 ft^2/ac, and SI = 70 respectively.

The study sites lie on Chestnut Ridge near the axis of the Chestnut Ridge Anticline, a broad gentle upfold that extends southwest from Pennsylvania across most of West Virginia (Hare 1957). In general, the bedrock is part of the Upper Connoquenessing sandstones of the Pottsville series, which include conglomeratic sandstones, thin coals, fire clay, and shale. Pottsville sandstones form the protective mantle at the top of Chestnut Ridge, and are highly resistant to erosion. Soils of both watersheds are classified in the DeKalb Series (Patton et al. 1959). Comparing soils commonly found in the northern mountain section of West Virginia, Auchmoody (1971) found that Dekalb soils formed from Pottsville material are likely to be nutrient deficient. These are loamy-skeletal, moderately deep and well-drained soils, formed in acid material weathered from sandstone. Strong fertility gradients in soil conditions exist even when parent materials are uniform (Boerner 1984). Thus Frank (1981) found that although soil classifications of the two watersheds were similar, soil fertility varied strongly with aspect. Higher soil values of Mn and K were associated with north- and northeast-facing slopes characteristic of WS1. Conversely, higher values of Fe occurred on south- and southwest-facing slopes, supplied by chemical weathering of parent material.

Slope-inclinations of the two watersheds are comparable. The average slope of WS1 is 17.5%, with a range of 12-33%, while WS2 averages 18.8%, with a range of 2-38% (Frank 1981). Elevation ranges from 2598 ft. above sea level at the northern end near the Sand Spring Fire Tower, to 1840 ft. near the confluence of Little Laurel Run and Little Laurel Creek.

METHODS

In August 1984, a weir was constructed on WS1 using the design of Whipkey (1961). A 120° V-notch control section was established, and an event recorder installed. Stream discharge data were processed at the Northeast Forest Experiment Station Laboratory, USDA Forest Service, in Parsons, WV, to produce values for daily and monthly streamflow. Streamflow data are supplemented by precipitation and climatic data, which are recorded daily at the nearby WVU Climate Station. Bulk samples of precipitation and streamwater grab samples from both watersheds have been collected continuously since October 1983, primarily at weekly intervals. At the time of streamwater sampling, maximum, minimum, and current water temperatures were also recorded from maximum-minimum thermometers placed in the stream.

The precipitation inputs to the study area were collected from a bulk sampler at the top of the ridge adjoining the two watersheds. Likens and Bormann (1995) suggest that dry deposition of Ca, Mg, Na, and K is probably a small fraction of total bulk deposition inputs, and thus this method is suitable for these dissolved substances and larger particles. However it is less efficient in collecting dry deposition from aerosols smaller than 1 m. Nitrogen gases and aerosols, for example, may be generated from biogenic activity and fossil fuel combustion, and are directly absorbed from the atmosphere by plant leaves and soil (Waring and Running 1998); nitrogen inputs may thus be underestimated by reliance on bulk collection.

Chemical analysis of the precipitation and streamwater samples was performed by the Analytical Laboratory of the College of Engineering and Mineral Resources, WVU. Elements analyzed include calcium (Ca^{+2}), potassium (K^{+}), magnesium (Mg^{+2}) and sodium (Na^{+}), which were analyzed by atomic absorption spectrophotometry (ASTM 1985). Phosphate (PO_4^{-3}), hydrogen (H^{+}), and nitrogen-nitrate (NO_3^{-}), were measured using standard methods for examination of water and wastewater (Am. Public Health Association 1965). Not all substances were measured in all years. Sulfate (SO_4^{-2}) was measured for two years (1984-1985), but was replaced by phosphate in 1986. Mass based inputs (kg/ha) of nutrients from precipitation were calculated by multiplying monthly rainfall volume (acre-inches) by the average monthly nutrient concentration (mg/l) of precipitation samples. Mass-based streamwater outputs were derived by multiplying average monthly streamwater nutrient concentrations (mg/L) for both watersheds by stream discharge (ft^3/sec mi^2) after the appropriate metric conversions.

Stream discharge data for WS1 are available for the period 1984-1994. In 1995, the weir in WS1 became dysfunctional and no discharge data have been measured since that time. We estimated monthly discharge for the period 1995-present by developing a series of regression equations utilizing the 10 years of streamflow data (1984-1994) as the dependent variable, and total monthly precipitation and average monthly temperature for the sample month, and the previous two months, as the independent variables (see Nik 1981). Equations were developed for each month, and take the form:

$$Q_m = k + a_1P_m + a_2P_{(m-1)} + a_3P_{(m-2)} + b_1T_m, + b_2T_{(m-1)} + b_3T_{(m-2)}$$

where Q_m, P_m, and T_m are estimated discharge, measured precipitation (in.) for the total sample intervals of that month, and average temperature (degrees C) for the calendar month (m), respectively; k is a constant, and $a_1 - b_3$ are partial regression coefficients; (m-1) and (m-2) are one and two months, respectively, prior to month m. Because the time intervals represented by streamwater grab samples overlap somewhat from one month to the next, precipitation values for this equation are generally, but not exactly equivalent to monthly totals. This equation yields a value in units of inches/day, that can be readily converted to ft^3/sec mi^2 by dividing the value by 0.03719 (Edwards 1986). Partial regression coefficients and R^2 values for the monthly equations are summarized in Table 1. Acceptable fits were derived for all months except April, November and December. June, July and August provided the best fits, with R^2values of 0.993, 0.954, and 0.954, respectively. An overall comparison of measured and predicted streamflow values using precipitation and temperature data yielded a linear regression with a correlation coefficient of 0.830 ($R^2 = 0.688$). The predictive power of the regression relationships, particularly with respect to April, November, and December, may be increased by addition of a term for evaporation, as suggest by Nik et al. (1983).

Results and discussion

1. **Streamflow and precipitation.** Mean monthly precipitation and measured streamflow values (1984-1994) are shown on Figure 1. For the ten years for which both precipitation and streamflow data are available, average annual precipitation was 47.6 in., while streamflow from WS1 averaged 36.9 in. On a monthly basis, precipitation varied relatively little. Maximum rainfall usually occurs from May to July, while November minimums average approximately 1.5 in. less. Seasonal fluctuations in stream discharge were much more pronounced, however, and show the strong influence of the biologic system in regulating its hydrologic output. Peak discharge generally occurs from November through March during leaf-off. Winter snowfall averages 72.5 in., and snowmelt during the peak flow period may result in monthly discharge values which temporarily exceed precipitation. In contrast, during the active growing season, transpiration by the forest canopy has a significant impact on the volume and timing of streamflow. The average total difference between annual precipitation and stream discharge was 10.6 in. for the period 1984-1994. Assuming that there is no deep storage of precipitation, this difference represents the evapotranspirational (ET) losses from the system, and because the land surface is largely forested, transpiration losses from the forest canopy account for the bulk of total evaporation. ET from these watersheds is somewhat below that reported in other eastern watershed studies. For example, Adams et al. (1993) measured 57.4" annual precipitation in the Fernow Experimental Forest in the mountains of eastern WV. Of that total, 25.2" left the system as streamflow, and the remainder (56%) was lost through evapotranspiration. In the northern hardwoods, Likens and Boremann (1995) estimate that 38% of precipitation is lost through evapotranspiration.

2. **Air and streamwater temperature.** Plots of average monthly air temperatures

at the WVU Forest weather station, and streamwater temperatures for the two watersheds are shown on Figure 2. Stream temperatures were highest from June through September, corresponding to the period of lowest flow. WS2 was consistently warmer than WS1, with an average difference of 3.7 degrees F. A maximum stream temperature difference of 4.5 degrees F occurs in April just before leaf-out, and the temperatures of the two streams are most similar during late summer. These differences are probably due in some measure to a lower leaf area index for oak forests on poorer sites that permits more sunlight to reach the forest floor. However, differences in aspect are probably more influential. Tajchman (1983) found that in July, southwest-facing slopes (WS2) received about the same amount of global radiation as a horizontal surface with an unobstructed horizon, and 25% more radiation than north-facing slopes (i.e., WS1). Slope-related differences are increased as slope-position decreases from ridge to valley floor.

The partial cutting in 1997 had no detectable effect on stream temperature of WS1, apparently because of stream shading by residual trees and understory vegetation composed primarily of witch hazel (*Hamamelis virginiana*) (Figure 3). This finding was consistent with a study of Kochenderfer, et al. (1997). In general, average weekly streamwater temperatures followed fluctuations in air temperature, although with a smaller range. Because of the high specific heat of water with respect to air, streams of both watersheds were slower to warm in the spring, and slower to cool in the fall. The overall similarities of air and stream temperature trends suggest that the effect of ground-water input on stream temperature is constant or relatively small.

3. **INPUT/OUTPUT NUTRIENT CONCENTRATIONS.** Table 2 shows the 16-year mean values and standard errors for nutrient input and output concentrations. Tables 3 and 4 summarize annual and monthly means. Generally, variability of concentration values was low over this sample period, and outputs showed more statistically significant changes than inputs. Over the 16 year study period, input concentrations of K and Na increased, while those for H^+, NO_3, and PO_4 decreased. (Unless otherwise noted, all time-related regressions have an F value significant at the $p \leq 0.05$ level). Significant increases in the output concentration of Na occurred for both watersheds, while the output of Ca increased only for WS2. Decreased PO_4 and NO_3 inputs were accompanied by decreases in output concentrations of these anions for both watersheds. The decline in precipitation-delivered H^+ ions is consistent with evidence from other sites in the eastern United States (Likens and Bormann 1995). However, the significance of the observed trend may be an artifact of two years (1985-1986) during which precipitation showed extremely low pH values of 3.6 and 3.5. These values are approximately three times more acidic than the 16-year mean (3.99), and when these two values were removed, the significance of the overall declining trend disappeared.

Sixteen-year output trends suggest that Ca concentration from WS2 is increasing, while K, PO_4, and NO_3 concentrations appear to be declining for both WS1 and WS2. The decrease in K concentrations (concentrations from both watersheds declined 1984-1999, although only the decline in WS2 was statistically significant) is particularly surprising in light of the overall increase of K concentrations in precipitation noted above. An increase

in streamwater Ca concentration was also found by Edwards and Helvey (1991) in the Fernow Experimental Forest during the period 1971-1987, although they also noted an increase in nitrate as well.

On a seasonal basis, input concentrations for all nutrients were slightly lower during winter (Fig. 4). This pattern may result, in part, from regional and seasonal patterns in air chemistry, and from differences in the scavenging efficiency between raindrops and snowfall. Snowflakes may be less efficient in removing materials from the atmosphere (Likens and Bormann 1997). In contrast, seasonal streamwater nutrient concentrations for both watersheds are remarkably stable, even though average monthly discharge of water may vary by a factor of 3, and considerably more during storm events. Output concentrations are somewhat reduced during periods of plant growth when nutrient demand is high, and increased during periods of vegetative dormancy. Nitrate concentrations show a slight peak in winter, due to increased nitrification associated with freezing and thawing of soils. However, the seasonal variations of NO_3 were much less than expected for a nutrient for which there is a high biologic demand. The lack of seasonality in NO_3 outputs has been associated with nitrogen saturation (Adams 1999, Peterjohn et al. 1996), a condition linked to chronically high atmospheric inputs of NO_3, and an inability of the biological system to fully utilize these inputs. With the exception of PO_4, concentrations increase in fall as leaf detritis is leached and decomposed, and nutrients enter streamwater.

A comparison of the annual pH of precipitation and streamwater of the two watersheds illustrates the strong impact of atmospheric acid inputs (Fig. 5). It also suggests that while soils of both watersheds are relatively effective in buffering the high acid loading, WS1 is somewhat more effective than WS2. The pH of precipitation averaged 3.99 over the study period, reaching as low 3.59 and 3.51 in 1985-86. Stream pH from WS2 averaged 4.42 during the same period, while the pH of WS1 averaged 5.23. Annual variations in the acidity of both watersheds closely paralleled changes in precipitation H^+ inputs; an examination of the curves shows similar responses by both streams, although at different magnitudes. Linear regression of H^+concentrations of WS1 and WS2 against H^+ inputs both yielded significant relationships ($p < 0.01$), suggesting that unlike cations, which are supplied primarily from secondary weathering, the output of H^+ from these watersheds is more closely linked to atmospheric inputs.

Particularly interesting is the strong dip in the pH of precipitation in 1986, and a similar decline for streams from both watersheds. Likens and Bormann (1995) suggest that increased acidity of precipitation at Hubbard Brook is the result of anthropogenic emissions of SO_2 and NO_x, which are hydrolized and oxidized to strong acids (H_2SO_4 and HNO_3) in the atmosphere. Once dissolved and then dissociated in rainwater, they provide a supply of H^+ ions and sulfur and nitrogen anions to forest soils. A linear regression of H^+ inputs (mg/l) against NO_3 inputs yielded a significant relationship ($R^2 = .29$, $F = 5.24$, $p < 0.04$). The coincidence of extremely low precipitation pH and high nitrate inputs (both concentrations and mass inputs) during 1986 and in subsequent years, suggest that H^+ and NO_3 are similarly coupled in the WVU Forest.

4. **Nutrient budgets**. In the two study watersheds, net gain and loss relationships found during the period 1984-1999 were consistent with the results noted by Hicks, et al. (1992). Three issues are relevant when considering input-output budgets: 1) the direction of net change (whether inputs are greater or less than output, 2) the magnitude of the net difference, and 3) long-range trends. Outputs exceeded inputs for Ca and Mg (Table 5, Figures 6, 8). For these, the percentage of nutrient exports supplied by precipitation inputs averaged 32% and 11%, respectively. Both nutrients have a high biological demand, and are rapidly leached from the forest canopy and leaf detritus. The additional output likely comes from soil release and chemical weathering of parent material. For example, Trettin et al. (1999) found that deep rooting was a major factor in compensating for cation loss in upper soil horizons of mature forests.

While the annual input of Ca showed no significant trend over the 16 year study period, the rate of Ca export from both watersheds, and thus the magnitude of the annual Ca budget deficit, increased. Regression of Ca outputs against time showed statistically significant increasing trends for both watersheds ($F = 12.9$ and 9.7, $p < 0.005$ and 0.01 for WS1 and WS2, respectively). This trend did not hold, however, for other cations such as K and Mg. For K and Na, budgets were essentially balanced although much more variable, with alternating periods of budget surpluses and deficits. Budgets were positive for PO_4 and NO_3 (Figure 8), and imports averaged 176% and 200%, respectively, of stream exports during 1984-1999. The magnitude of the surplus for these two nutrients varied considerably during the study period. During 1993-1994, inputs were nearly 4x greater than exports. These results suggest that these nutrients are accumulating in the two watersheds, results that are consistent with other watershed studies in the eastern United States (Likens and Bormann 1995, and Adams 1999). Surprisingly, this accumulation occurs at the same time as inputs of PO_4 and NO_3 showed a gradual 16-year decline (Figure 6). The decline of NO_3 mass inputs parallels the decline in NO_3 concentration of precipitation, however the reasons for this trend are unclear. Nationally, most studies show an increase in NO_3 deposition (Likens and Bormann 1995, and Adams 1999), accompanied by a decrease in atmospheric deposition of base cations such as Ca (Hedin et al. 1994, Likens et al. 1996). Forecasts predict N deposition will further increase by 25% during the next 25 years (Galloway et al. 1995).

One issue of interest was the impact of the 1997 harvest on the nutrient relations of WS1. Road building and soil disturbance associated with harvesting has been associated with increased erosion and stream sedimentation (Kochenderfer et al. 1997). The presence of logging slash may provide a temporary flush of nutrients as it decomposes, and removal of forest cover also reduces the transpirational demand and increases stream flow during the growing season. Since streamflow largely determines nutrient output, this may also lead to increased nutrient losses from disturbed watersheds. Increased NO_3 losses, in particular, are often associated with disturbances (Vitousek and Melillo 1979). Preliminary results of pre- (1984-1996) and post-harvesting (1998-1999) outputs are mixed. Using t-tests, annual streamwater nutrient concentrations and mass outputs of WS1 for the pre- and post harvesting periods were compared. For nutrient

concentrations, Na outputs increased ($t = -5.22$, $P < 0.01$) and PO_4 declined ($t = 2.56$, $p<0.05$), however these trends are consistent with the entire 16 year study period, and parallel changes that occurred in WS2 where no harvesting took place. For mass outputs, two significant changes were found. Output of K and Na were both greater after harvest ($t = -5.58, -11.67$, $p < 0.005, 0.001$, respectively), while no comparable changes occurred for other base cations or anions. Interpretation of these results are complicated by the relatively short time period representing post-harvest data, and by the fact that streamflow was estimated using regression equations based on full canopy cover during the period 1984-1994.

For nutrients with balanced (Na) or positive budgets (PO_4, NO_3), atmospheric inputs of those elements accounted for most of their annual variability over the 16-year study period. This relationship was particularly strong for total inputs (kg/ha) of H^+ in WS1. Multiple regression of H^+ output against H^+ and NO_3 inputs yielded an R^2 of 0.92 ($F = 63.09$, $p < 0.001$). This relationship between inputs and outputs did not hold for cations (Ca, Mg) with negative budgets.

Seasonally, inputs showed little variation (Table 6, Fig. 7). All nutrient outputs exhibited a strong seasonal distribution that corresponded to the period of nutrient uptake associated with the active growing season. Outputs of Ca and Mg exceeded inputs for each month, while for K and PO_4, inputs were greater than outputs from May-November. Peak outputs generally occurred during the dormant season, November-April, and there was a sharp decline during June-September. Trees are relatively dormant from October through April, and increased nutrient output during this period reflects metabolic activity and low levels of root uptake. Low exports during the growing season are in part, associated with lower streamflow during these months, particularly August-September, although there were few significant correlations when annual totals of nutrient exports and streamflow were compared. The seasonal trend in outputs was strongest for those nutrients for which there is a relatively high biological demand such as Ca, Mg, and NO_3. Nitrate exports, for example, varied by a factor of ten between peak output in February and minimum output in August, and these results countered the absence of a strong seasonal trend for NO_3 stream concentrations. Seasonality was weaker for Na, which is less important in plant physiological processes, and not selectively taken up and stored in plant tissues. Finally, outputs for all nutrients increased between September-October, the period leaf-fall and decomposition of leaf litter on the forest floor.

Stream outputs for all nutrients were also consistently greater from WS1 than WS2; paired t-tests yield significant results at $p < 0.05$ (Table 5, Figure 6). Thus for nutrients such as Ca and Mg that showed negative budgets, deficits were greater for WS1. Conversely, for those nutrients (PO_4, NO_3) that showed a net gain, accumulation was greater on WS2.

Site characteristics and soil fertility, litter quality and decomposition rates, and to a lesser degree, species-biomass nutrient concentrations together are probably responsible for differences in nutrient output rates of the two watersheds (Mudrick et al. 1994). Johnson

and Todd (1990) found that yellow-poplar stands had greater total N, total P, and exchangeable Ca and Mg than oak-hickory and chestnut oak stands, and that total leaching losses were as much as 37% greater from yellow-poplar forests (Johnson et al. 1985). With the exception of Ca (highest in chestnut oak forest), however, variability of nutrient concentrations of live vegetation was minor, and that litter quality and soil pools were largely responsible for site differences. They concluded that slope position and microtopography were more important in determining the rate of nutrient return and overall nutrient status. Boerner (1984) reached a similar conclusion when comparing foliar N and P concentrations of individuals of the same species between southwest-facing and northeast-facing sites. Trees on nutrient-poor, southwest-facing sites were more conservative of nutrients and produced nutrient-poor litter; they had lower maximum foliar N and P concentrations and resorbed a larger proportion of N and P prior to litterfall than did individuals of the same species on mesophytic sites. South- and west-facing slopes are generally warmer, especially in winter (Tajchman 1983); they also have deeper, more heavily weathered and leached soils (Boerner 1984). Where parent materials are similar between sites, north- and east-facing slopes have higher organic matter content, pH, base saturation, and more extractable N than south- and west-facing slopes. In the Little Laurel Run study area, Hicks and Frank (1984) found significant positive correlations between transformed aspect and CEC, organic matter, P, K, Ca, Mg, and total base saturation for soil A, to a lesser extent, B horizons. They attributed this difference in part to a more rapid decomposition and recycling rate on north- and east-facing sites.

Summary

Precipitation entering these two watersheds of the West Virginia University Forest undergoes both qualitative and quantitative changes as it passes through these systems. Precipitation falls at a predictable rate as a dilute, acidic (pH ~ 4.0) solution, enriched in PO_4 and NO_3, and leaves as a less acidic but more concentrated solution of Ca and Mg. These relationships are reflected in nutrient budgets. The two watersheds are accumulating PO_4 and NO_3, and exporting Ca and Mg. While the emphasis in this report has been the detection of changes in inputs and outputs and trends over time, perhaps most notable is the stability of the system. By and large, conclusions reached after the first seven years of study (Hicks et al 1992) are confirmed by an additional nine years of data collection.

The certainty attached to the conclusions derived from this study rest on the soundness of field sampling methods, chemical analysis of samples, and computational techniques, and each is a potential source of error. Field sampling was usually conducted weekly, but there are periods during which few, or no field collections were made. In addition, several laboratories performed chemical analysis, introducing possible sources of error. Degrees of confidence have been attached to some of the calculations discussed in this report, but for sampling and analysis methods, no degree of certainty can be calculated. The accuracy of the calculation of stream mass outputs, in particular, rests on streamflow values estimated for the period since 1994. These estimates are derived from regression

equations using combinations of monthly precipitation and temperature. The goodness of fit of these equations varied when predicted values were compared to actual stream flow measured while the weir was still functional; April and December, in particular, had low R^2 values, which may have resulted in under- or over-estimations of stream outputs. With this note of caution in mind, we summarize the following 16-year trends:

1. The average annual precipitation and streamflow for the period 1984-1994 were 47.6 in. and 36.9 in., respectively. Seasonal fluctuations in stream discharge were much greater than those for precipitation, reflecting the biological processes of the forest during the growing season.
2. The average stream temperature of WS2 averaged 3.7 degrees F greater than that for WS1, and differences were greatest in April before leaf-out. This disparity can largely be attributed to differences in solar radiation related to aspect. Removal of trees in WS1 in 1997 did not result in a notable increase in stream temperature.
3. Nutrient concentrations of precipitation showed an increase of K and Na over the study period, and a decrease in NO_3 and PO_4. There was a statistically significant decline in H^+ inputs, however the trend was largely a consequence of two years (1985-1986) during which the pH of precipitation was 3x more acidic than the 16-year mean. Lower H^+ inputs did not lead to significant improvements in streamwater pH. Ca and Na output concentrations from both watersheds increased, although for Ca, the trend was significant only for WS2. Declines in NO_3 and PO_4 input concentrations were paralleled by declines in output concentrations of these nutrients.
4. Nutrient input-output budgets for Ca and Mg remained negative, indicating that the two watersheds are exporting more of these elements than they are receiving from precipitation. This is consistent with findings of other studies in the eastern United States. Budgets for K and Na were more or less balanced. The budgets for NO_3 and PO_4 showed large surpluses, despite declining precipitation and streamwater output concentrations over the study period. For those nutrients that showed either a balanced budget (Na) or a surplus (H^+, NO_3, PO_4), atmospheric input of the respective ions accounted for a large proportion of their annual variability. For those nutrients with negative budgets (Ca, Mg), the amount of outs showed little association with inputs.
5. After the 1997 partial harvest in WS1, stream concentrations of Na increased and those for PO_4 declined; both results were consistent with 16-year trends and also occurred in the uncut WS2. Mass outputs from WS1 increased for K and Na. However, these results are tentative because of the short time period of comparison, and the fact that they were derived from calculated streamflow values based on full-canopy cover. Outputs of other nutrients did not show significant changes attributable to the partial harvest.
6. The budgets for all nutrients were strongly seasonal. Monthly inputs varied little, but outputs were significantly greater in winter and early spring, and lower during the growing season. This reflects both the seasonal hydrologic pattern of the watersheds, increased uptake of nutrients during the growing

season, and increased availability of nutrients from the decomposition of litter after leaf-fall.

7. Despite declining H^+ inputs, the pH of precipitation remained very acidic, and there were no significant reductions in stream pH. WS1 had a much higher pH than WS2, and was consistently higher in its output of nutrients than WS2. The latter may be related to differences in vegetative cover and litter quality between yellow-poplar and oak-dominated forests. It is also a consequence of inherent soil characteristics, and the rate of litter decomposition and nutrient cycling associated with differences in slope-aspect.

Sources cited

Adams, M. B. 1999. Acidic deposition and sustainable forest management in the central Appalachians, USA. For. Ecol. Manage. 122:17-28.

Adams, M. B., J. N. Kochenderfer, F. Wood, T. R. Angradi, and P. Edwards. 1994. Forty years of hydrometerological data from the Fernow Experimental Forest, West Virginia. Gen. Tech. Rep. NE-184. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Anonymous, 1965. Standard methods for examination of water and wastewater, including bottom sediments and sludges. 12th ed. American Public Association, New York, NY.

Annonymous. 1985. Annual book of ASTM standards. American Society for Testing and Materials, Philadelphia, PA.

Auchmoody, L. R. 1972. Nutrient properties of five West Virginia forest soils. Research Note NE-145, USDA Forest Service, Upper Darby, PA.

Boerner, R. E. 1985. Nutrient fluxes in litterfall and decomposition in four forests along a gradient of soil fertility in southern Ohio. Can. J. For. Res. 14:794-802.

Carvell, K. L. 1983. A summary of 1973-1982 weather data from the West Virginia University Forest. West Virginia Forestry Notes, circular 123, West Virginia Univ. Agricultural and Forestry Experiment Station, Morgantown, WV.

Edwards, P. J. 1986. Conversion factors and constants used in forestry, with emphasis on water and soil resources. NE-GTR-113, USDA Forest Service, Northeastern Forest Experiment Station, Broomall, PA.

Edwards, P. J. and J. D. Helvey. 1991. Long-term ionic increases from a central Appalachian forested watershed. J. Environ. Qual. 20:250-255.

Federer, C. A, J. W. Hornbeck, L. M. Tritton, C. W. Martin, R. S. Pierce, and C. T. Smith, 1989. Long-term depletion of calcium and other nutrients in eastern U. S. Forests. Environ. Manage. 13:593-601.

Frank, P. S., Jr. 1981. Forest biomass predicted by soil-site factors. Ph.D. dissertation, West Virginia University. 114 pp.

Galloway, J. N., W. H. Schlesinger, J. Levy, A. Michaels, and J. L. Schnoor. 1995. Nitrogen fixation: anthropogenic enhancement, environmental response. Global Biogeochem. Cycles. 9:235-252.

Hare. C. E. 1957. Geology of Coopers Rock State Forest and Mont Chateau State Park, WV. State Park Series Bulletin 5, West Virginia Geologic and Economic Survey, Morgantown. WV.

Hedin. L. O., L. Granat. G. E. Likens. T. A. Buishand, J. N. Galloway, T. J. Butler, and H. Rodhe. 1994. Steep declines in atmospheric base cations in regions of Europe and North America. Nature 367:351-354.

Hicks, R. R. Jr., and P. S. Frank, Jr. 1984. Relationship of aspect to soil nutrients, species importance, and biomass in a forested watershed in West Virginia. For. Ecol. Manage. 8:281-291.

Hicks. R. R. Jr., D. Mudrick. and E. Townsend. 1992. Nutrient fluxes for two small watersheds: seven year results from the West Virginia University Forest. Bulletin 707, West Virginia University Agricultural and Forestry Experiment Station. Morgantown. WV.

Helvey, J. D. and S. H. Kunkle. 1986. Input-output budgets of selected nutrients on an experimental watershed near Parsons. WV. Res. Pap. NE-584. USDA Forest Service, Northeastern Experiment Station, Broomall, PA.

Johnson. D. W.. D. D. Richter, G. M. Lovett, and S. E. Lindberg. 1985. The effects of atmospheric deposition on potassium, calcium, and magnesium cycling in two deciduous forests. Can. J. For. Res. 15:773-782.

Johnson. D. W. and D. E. Todd. 1990. Nutrient cycling in forests of Walker Branch Watershed. Tennessee: roles of uptake and leaching in causing soil changes. J. Environ. Qual. 19:97-104.

Likens, G. E.. C. T. Driscoll. and D. C. Buso. 1996. Long-term effects of acid rain: response and recovery of a forest ecosystem. Science 272:244-246.

Likens. G. E. and F. E. Bormann. 1997. Biogeochemistry of a forested ecosystem. 2nd ed. Springer, New York, NY

Long, R. P., S. B. Horsley, and P. R. Lilja. 1997. Impact of forest liming on growth and crown vigor of sugar maple and associated hardwoods. Can. J. For. Res. 27:1560-1573.

Kochenderfer, J. N., P. J. Edwards, and F. Wood. 1997. Hydrologic impacts of logging an Appalachian watershed using West Virginia's Best Management Practices. North. J. App. For. 14:207-218.

Mudrick. D. A.. H. Macsood. R. R. Hicks. Jr., and E. C. Townsend. 1994. Decomposition of leaf litter in an Appalachian forest: effects of leaf species, aspect, slope position and time. For. Ecol. Manage. 68:231-250.

Nik, A. R. H. 1981. Normal evaporation and discharge from an undisturbed forested catchment. M. S. Thesis. West Virginia University. 104 pp.

Nik, A. R. H, R. Lee and J. D. Helvey. 1983. Climatological watershed calibration. Paper No. 82078, Water Resources Bulletin. American Water Resources Association 19:7-50.

Patton, B. J., W. W. Beverage, and G. G. Pohlman. 1959. Soil survey of Preston County, West Virginia. USDA SCS, West Virginia Agr. Exp. Sta., Series 1954, No. 3.

Peterjohn, W. T., M. B. Adams, and F. S. Gilliam. 1996. Symptoms of nitrogen saturation in two central Appalachian hardwood forest ecosystems. Biogeochem. 35:507-522.

Ranger, J. and M.-P. Turpault. 1999. Input-output nutrient budgets as a diagnostic tool for sustainable forest management. For. Ecol. Manage. 122:139-154.

Schlesinger, W. H. 1997. Biogeochemistry: an analysis of global change. Academic Press, San Diego, CA.

Tajchman, S. J. 1983. Solar radiation climate of a forested catchment. West Virginia Forestry Notes, circular 123, West Virginia Univ. Agricultural and Forestry Experiment Station, Morgantown, WV.

Vitousek, P. M. and J. M. Melillo. 1979. Nitrate losses from disturbed watersheds: patterns and mechanisms. Forest Sci. 25:605-619.

Waring, R. H. and S. W. Running. 1998. Forest Ecosystems: analysis at multiple scales. 2nd. Ed. Academic Press, San Diego, CA.

Whipkey, R. Z. 1961. Plywood cutoff walls for temporary weirs. Cent. States For. Exp. Sta. Note No. 150. 2pp.

Figure captions

Figure 1. Mean monthly hydrologic data for precipitation and stream discharge, 1984-1994.

Figure 2. Comparison of mean monthly air temperature, and mean monthly streamwater temperatures for WS1 and WS2, 1990-1999.

Figure 3. Average annual streamwater temperatures of WS1 and WS2, 1990-1999.

Figure 4. Comparison of average seasonal nutrient concentrations in precipitation and streamflow (WS1) 1984-1999. (winter = December-February, spring = March-May, summer = June August, and fall = September-November).

Figure 5. Comparison of precipitation (C1) and streamwater (WS1, WS2) pH and H^+ ion concentration, 1984-1999.

Figure 6. Annual inputs and outputs (kg/ha) for WS1 and WS2, 1984-1999.

Figure 7. Average monthly nutrient inputs and outputs (kg/ha), WS1 and WS2, 1984-1999.

Figure 8. Nutrient budgets for WS1 and WS2, 1984-1999. Positive budgets indicate net accumulation, while negative budgets indicate net loss.

Table 1. Multiple regression coefficients for predicting stream discharge from monthly precipitation and temperature, WS1 and WS2, 1984-1994.

Month	k	a_1	a_2	a_3	b_1	b_2	b_3	R^2
Jan	-0.864	1.566	0.351	-0.036	0.105	0.000	0.027	89.0
Feb	1.421	0.254	1.704	-0.315	0.201	0.071	0.127	92.7
Mar	1.734	1.473	-0.692	0.001	0.347	-0.812	0.341	79.0
Apr	5.734	0.069	0.132	-0.420	-0.101	-0.205	-0.396	45.9
May	3.482	0.621	0.108	0.532	-0.088	-0.648	0.408	85.4
June	1.460	0.707	0.048	-0.216	-0.013	-0.069	-0.122	99.3
July	5.224	0.324	0.091	0.020	-0.001	-0.255	-0.138	95.4
Aug	1.517	1.036	0.040	-0.066	0.786	-0.462	-0.608	95.4
Sep	4.154	0.203	0.013	-0.146	0.037	-0.240	0.004	72.6
Oct	-7.638	0.404	0.575	0.166	0.219	-0.281	0.361	78.9
Nov	-3.988	-0.147	0.452	0.291	-0.035	0.064	0.218	62.5
Dec	0.582	0.735	0.133	0.040	-0.054	-0.025	0.034	38.8

Discharge (Q_m) = $k + a_1P_{(m)} + a_2P_{(m-1)} + a_3P_{(m-2)} + b_1T_{(m)} + b_2T_{(m-1)} + b_3T_{(m-2)}$, where $P_{(m)}$ and $T_{(m)}$ are precipitation (in.) totals and temperatures (C) averages for the current month, and (m-1) and (m-2) designate precipitation and temperature values for one and two months prior, respectively.

Table 2. Mean nutrient concentrations (mg/l) and standard error (SEM) for precipitation (Clearing, C1) and streamwater (WS1, WS2) for the period, 1984-1999.

	C1			WS1			WS2		
	Mean	SEM	SEM/Mean, %	Mean	SEM	SEM/Mean, %	Mean	SEM	SEM/Mean, %
Ca	0.689	0.047	6.8	2.127	0.062	2.9	1.933	0.052	2.7
K	0.496	0.054	10.9	0.539	0.017	3.2	0.474	0.026	5.6
Mg	0.114	0.011	9.5	1.335	0.030	2.2	0.918	0.015	1.6
Na	0.552	0.040	7.2	0.630	0.022	3.6	0.455	0.018	4.0
*PO_4	0.730	0.044	6.0	0.487	0.036	7.3	0.479	0.036	7.5
NO_3	1.231	0.060	4.9	0.806	0.042	5.2	0.639	0.033	5.1
H^+	1.0E-04	9.3E-06	9.2	5.7E-06	7.1E-07	12.3	3.9E-05	2.5E-06	6.4
pH	3.99	--	--	5.23	--	--	4.42	--	--

*1986-1999

Table 3. Mean annual element concentrations (mg/l), clearing (C1) and watershed 2 (WS1) and watershed 1 (WS2), 1984-1999.

	Location	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Aver.
	C1	0.37	0.54	0.63	0.41	1.28	0.20	0.20	0.56	0.67	0.54	0.55	0.63	0.89	0.91	0.83	1.02	0.64
Ca	WS1	1.82	1.96	2.14	1.98	2.46	1.36	1.71	2.95	2.62	2.55	2.32	2.37	2.47	2.43	2.44	2.27	2.24
	WS2	1.35	1.52	1.88	1.81	2.36	1.12	1.48	2.45	2.29	2.19	1.98	2.11	2.20	2.21	2.15	2.01	1.94
	C1	0.15	0.17	0.31	0.39	0.54	0.56	0.39	0.32	0.72	0.68	0.65	0.41	0.25	0.32	0.91	0.95	0.48
K	WS1	0.79	0.67	0.61	0.63	0.52	0.49	0.55	0.70	0.57	0.46	0.41	0.47	0.47	0.49	0.60	0.65	0.57
	WS2	0.63	0.50	0.88	0.39	0.44	0.40	0.47	0.66	0.47	0.36	0.30	0.41	0.36	0.41	0.48	0.41	0.47
	C1	0.05	0.17	0.14	0.06	0.09	0.03	0.05	0.06	0.14	0.12	0.14	0.12	0.07	0.07	0.11	0.33	0.11
Mg	WS1	1.48	1.46	1.47	1.81	1.45	0.73	1.22	1.56	1.46	1.41	1.39	1.46	1.39	1.38	1.39	1.32	1.40
	WS2	0.98	1.02	1.05	1.11	0.84	0.46	0.80	1.03	0.97	0.93	0.88	1.00	0.94	0.93	0.90	0.86	0.92
	C1	0.02	0.16	0.55	0.48	0.81	0.32	0.21	0.63	0.66	0.43	0.32	0.50	0.87	0.88	0.74	0.86	0.53
Na	WS1	0.30	0.39	0.67	0.52	0.55	0.59	0.54	0.78	0.69	0.62	0.48	0.73	0.89	0.93	0.98	1.14	0.67
	WS2	0.24	0.32	0.58	0.36	0.34	0.35	0.33	0.49	0.40	0.36	0.25	0.45	0.69	0.69	0.78	0.82	0.46
	C1	NA	0.16	0.33	1.16	1.50	0.89	0.94	1.15	0.98	0.54	0.57	0.51	0.39	0.29	0.51	0.55	0.70
*PO4	WS1	NA	0.11	0.12	1.03	1.36	0.71	0.96	1.02	0.44	0.21	0.32	0.16	0.28	0.20	0.29	0.20	0.49
	WS2	NA	0.24	0.12	1.03	1.26	0.64	0.89	0.98	0.41	0.16	0.26	0.16	0.27	0.19	0.21	0.20	0.47
	C1	0.74	0.99	2.39	1.79	1.62	1.17	1.01	1.16	1.27	1.08	1.03	0.99	0.91	0.99	0.90	1.18	1.20
NO3	WS1	0.50	1.21	1.70	1.32	1.33	0.79	1.11	1.18	0.45	0.49	0.39	0.52	0.54	0.54	0.68	0.75	0.84
	WS2	0.32	0.77	1.17	1.13	1.19	0.62	0.86	0.92	0.34	0.28	0.28	0.50	0.49	0.41	0.40	0.43	0.63
	C1	4.04	3.59	3.51	4.11	4.01	4.17	4.14	4.13	4.12	4.06	4.05	3.88	4.06	4.16	4.51	4.40	3.99
pH	WS1	5.35	4.71	4.82	5.47	5.61	5.09	5.47	5.75	5.44	5.21	5.16	5.07	5.17	5.59	5.90	5.74	5.23
	WS2	4.71	4.37	4.10	4.61	4.57	4.52	4.65	4.68	4.45	4.32	4.42	4.08	4.17	4.48	4.85	4.63	4.42

*1986-1999

Table 4. Average monthly input and output nutrient concentrations (mg/l), for clearing (C1) and watershed 1 (WS1) and watershed 1 (WS2), 1984-1999.

	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aver.
	C1	0.50	0.49	0.58	0.63	0.64	0.65	0.62	0.67	0.62	0.85	1.10	0.50	0.65
Ca	WS1	2.54	2.39	2.31	2.07	1.97	1.84	1.71	1.62	1.92	2.43	2.54	2.45	2.15
	WS2	2.17	2.16	2.04	1.85	1.81	1.64	1.56	1.62	1.93	2.04	2.20	2.09	1.93
	C1	0.22	0.23	0.21	0.21	0.36	0.52	0.45	0.43	0.58	1.35	1.25	0.35	0.51
K	WS1	0.50	0.59	0.68	0.56	0.56	0.59	0.52	0.45	0.49	0.60	0.62	0.48	0.55
	WS2	0.44	0.43	0.48	0.51	0.49	0.43	0.39	0.36	0.42	0.45	0.81	0.41	0.47
	C1	0.07	0.09	0.10	0.06	0.09	0.17	0.09	0.08	0.10	0.15	0.24	0.06	0.11
Mg	WS1	1.46	1.47	1.39	1.41	1.40	1.36	1.23	1.10	1.29	1.40	1.39	1.44	1.36
	WS2	0.96	0.96	0.94	0.91	0.92	0.88	0.79	0.82	0.89	0.92	1.00	0.98	0.91
	C1	0.63	0.61	0.55	0.50	0.44	0.43	0.32	0.47	0.38	0.49	0.80	0.75	0.53
Na	WS1	0.64	0.63	0.66	0.67	0.60	0.61	0.54	0.50	0.51	0.67	0.63	0.61	0.61
	WS2	0.39	0.43	0.44	0.44	0.44	0.48	0.43	0.55	0.45	0.51	0.45	0.45	0.46
	C1	0.57	0.55	0.64	0.60	0.83	0.83	0.81	0.69	0.60	1.03	0.95	0.72	0.73
*PO4	WS1	0.45	0.51	0.51	0.55	0.61	0.64	0.72	0.50	0.43	0.46	0.50	0.48	0.53
	WS2	0.44	0.42	0.44	0.46	0.51	0.52	0.63	0.58	0.48	0.43	0.43	0.46	0.48
	C1	1.00	1.46	1.40	1.19	1.13	1.32	1.14	0.94	1.08	1.55	1.66	0.88	1.23
NO3	WS1	0.84	0.83	0.78	0.73	0.66	0.63	0.63	1.08	0.82	0.75	0.94	0.84	0.79
	WS2	0.63	0.83	0.71	0.65	0.63	0.46	0.63	0.66	0.62	0.60	0.59	0.66	0.64
	C1	4.08	4.04	4.12	4.08	4.06	3.80	3.88	3.82	3.96	4.20	3.96	4.03	4.00
pH	WS1	5.23	5.03	5.35	5.33	5.54	5.32	5.46	5.21	5.15	5.02	5.25	5.04	5.22
	WS2	4.48	4.41	4.49	4.48	4.47	4.46	4.27	4.20	4.39	4.46	4.43	4.44	4.40

*1986-1999

Table 5. Annual sums of element inputs (C1) and outputs (WS1 and WS2), (kg/ha), 1984-1999.

	Location	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Aver.
	C1	5.08	NA	9.14	2.41	11.57	2.56	2.17	4.64	5.15	5.70	5.57	6.50	11.50	8.49	8.32	9.50	6.55
Ca	WS1	17.10	NA	18.48	14.20	23.51	19.15	20.93	19.73	25.95	19.74	21.21	27.56	23.05	27.07	23.44	21.51	21.51
	WS2	12.90	NA	17.34	13.96	22.22	15.65	18.12	23.31	22.94	17.07	18.39	25.40	20.46	25.34	20.41	18.93	19.50
	C1	1.96	NA	3.98	4.62	5.86	6.60	3.93	2.27	6.75	9.79	4.01	3.52	3.03	2.90	7.94	4.13	4.75
K	WS1	7.45	NA	3.54	4.19	3.65	6.55	6.44	4.23	5.77	3.46	3.49	5.08	4.71	5.22	5.35	6.75	5.06
	WS2	5.94	NA	3.29	3.14	3.22	5.44	5.85	5.28	4.86	2.96	2.85	4.42	3.81	4.62	4.58	3.95	4.28
	C1	0.64	NA	2.09	0.45	0.81	0.45	0.55	0.49	1.21	1.35	1.62	1.14	0.87	0.65	1.05	2.60	1.07
Mg	WS1	13.35	NA	15.24	13.82	12.12	9.65	13.53	11.12	14.36	10.98	12.50	17.25	13.18	14.89	13.47	12.20	13.18
	WS2	8.90	NA	11.12	10.05	7.41	6.03	8.98	9.95	9.44	7.48	7.99	12.01	8.73	10.15	8.83	8.11	9.01
	C1	0.35	NA	7.94	3.91	7.83	3.91	2.69	5.07	5.28	4.59	3.56	5.73	10.96	8.24	8.18	7.90	5.74
Na	WS1	2.45	NA	3.70	3.77	4.09	8.03	6.41	4.68	7.37	4.72	3.19	8.29	8.73	9.66	9.93	11.24	6.42
	WS2	2.07	NA	2.79	3.12	2.47	4.92	3.81	3.56	4.23	2.57	1.75	4.51	6.61	7.25	7.76	7.63	4.34
	C1	NA	NA	4.73	14.01	16.70	12.46	12.24	10.13	7.57	6.63	7.27	5.44	4.90	2.62	6.14	2.62	8.10
*PO4	WS1	NA	NA	0.93	6.81	10.74	10.26	10.46	7.12	4.42	1.11	3.28	2.18	2.00	1.98	2.62	2.06	4.71
	WS2	NA	NA	0.97	6.72	10.03	9.05	9.70	8.45	4.04	0.96	2.80	2.06	2.09	2.18	2.02	1.89	4.50
	C1	NA	NA	35.92	18.15	18.28	16.40	12.06	9.79	10.44	12.35	11.78	9.67	12.06	9.10	10.00	7.74	13.84
NO3	WS1	NA	NA	15.47	9.76	11.08	10.61	13.65	9.06	5.08	4.22	3.22	5.06	5.24	5.88	5.73	7.62	7.98
	WS2	NA	NA	12.71	8.84	9.77	8.82	10.45	9.82	4.02	2.54	2.44	6.62	5.23	4.58	4.09	4.22	6.73
	C1	8.E-04	3.E-03	5.E-03	1.E-03	1.E-03	1.E-03	9.E-04	6.E-04	8.E-04	9.E-04	1.E-03	1.E-03	1.E-03	6.E-04	4.E-04	4.E-04	1.E-03
H+	WS1	9.E-06	9.E-05	2.E-04	4.E-05	2.E-05	9.E-05	5.E-05	2.E-05	4.E-05	5.E-05	9.E-05	1.E-04	9.E-05	4.E-05	1.E-05	2.E-05	6.E-05
	WS2	2.E-04	2.E-04	4.E-04	2.E-04	2.E-04	4.E-04	3.E-04	2.E-04	3.E-04	3.E-04	3.E-04	1.E-03	7.E-04	4.E-04	2.E-04	2.E-04	4.E-04

*1986-1999

Table 6. Average monthly inputs (C1) and outputs (WS1 and WS2) (kg/ha), 1984-1999.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Aver.
Ca	C1	0.44	0.38	0.65	0.65	0.62	0.49	0.70	0.53	0.50	0.65	0.59	0.37	0.55
	WS1	3.60	3.67	3.80	2.69	1.49	0.54	0.55	0.39	0.25	0.79	1.27	2.44	1.79
	WS2	2.94	3.25	3.35	2.38	1.32	0.46	0.46	0.31	0.22	0.71	1.12	2.19	1.56
K	C1	0.20	0.20	0.24	0.18	0.33	0.40	0.49	0.33	0.54	0.86	0.51	0.29	0.38
	WS1	0.68	0.74	1.01	0.69	0.44	0.20	0.16	0.10	0.06	0.22	0.29	0.50	0.43
	WS2	0.62	0.64	0.75	0.61	0.39	0.13	0.11	0.06	0.04	0.17	0.24	0.45	0.35
Mg	C1	0.06	0.07	0.13	0.07	0.09	0.12	0.10	0.06	0.08	0.09	0.19	0.06	0.09
	WS1	1.97	2.15	2.21	1.74	1.06	0.42	0.36	0.25	0.16	0.46	0.84	1.59	1.10
	WS2	1.31	1.43	1.49	1.12	0.71	0.27	0.23	0.15	0.10	0.31	0.56	1.08	0.73
Na	C1	0.60	0.52	0.67	0.42	0.29	0.32	0.38	0.41	0.31	0.39	0.49	0.63	0.45
	WS1	0.89	1.02	1.16	0.84	0.52	0.19	0.16	0.12	0.07	0.25	0.38	0.66	0.52
	WS2	0.58	0.69	0.74	0.53	0.34	0.13	0.12	0.08	0.04	0.17	0.26	0.45	0.34
*PO4	C1	0.44	0.50	0.58	0.42	0.72	0.67	0.73	0.55	0.58	0.77	0.41	0.72	0.59
	WS1	0.52	0.67	0.69	0.55	0.40	0.17	0.15	0.09	0.10	0.18	0.24	0.49	0.35
	WS2	0.53	0.58	0.62	0.48	0.36	0.16	0.13	0.09	0.09	0.19	0.20	0.46	0.33
NO3	C1	0.87	1.43	1.30	1.28	1.21	1.13	1.31	0.80	0.86	1.31	0.85	0.74	1.09
	WS1	1.15	1.48	1.29	0.89	0.58	0.20	0.22	0.11	0.10	0.38	0.45	0.86	0.64
	WS2	0.89	1.34	1.02	0.71	0.49	0.15	0.18	0.08	0.08	0.27	0.33	0.72	0.52
H+	C1	6.5E-05	8.6E-05	7.8E-05	8.9E-05	9.6E-05	1.3E-04	1.8E-04	1.3E-04	1.0E-04	7.4E-05	1.3E-04	7.4E-05	1.0E-04
	WS1	8.0E-06	1.7E-05	8.2E-06	7.2E-06	2.3E-06	1.8E-06	1.4E-06	1.0E-06	3.4E-07	2.2E-06	3.7E-06	9.9E-06	5.3E-06
	WS2	4.7E-05	6.8E-05	5.9E-05	4.3E-05	2.7E-05	1.1E-05	2.1E-05	7.9E-06	3.1E-06	1.2E-05	2.2E-05	4.0E-05	3.0E-05

*1986-1999

Figure 1. Mean monthly hydrologic data for precipitation and stream discharge, 1984-1994.

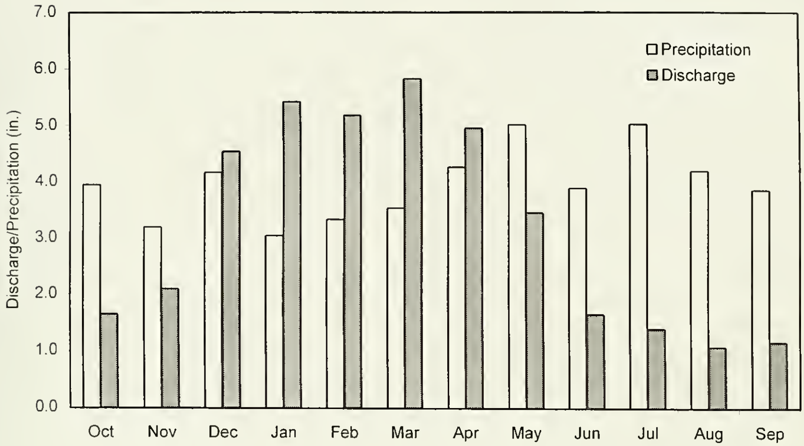


Figure 2. Comparison of mean monthly air temperature, and mean monthly streamwater temperatures for WS1 and WS2, 1990-1999.

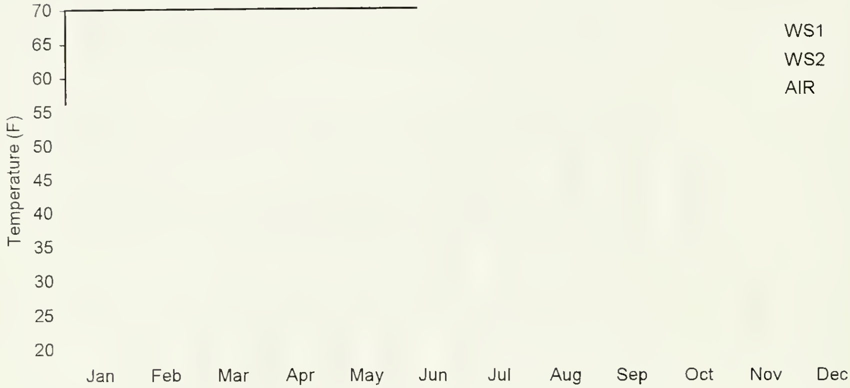


Figure 3. Average annual streamwater temperatures of WS1 and WS2, 1990-1999.

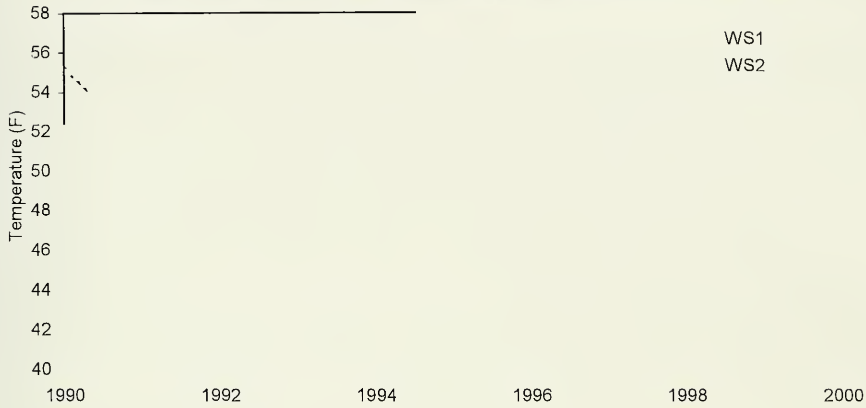


Figure 4. Comparison of average seasonal nutrient concentrations in precipitation and streamflow (WS1) 1984-1999. (winter = December-February, spring = March-May, summer = June-August, and fall = September-November).

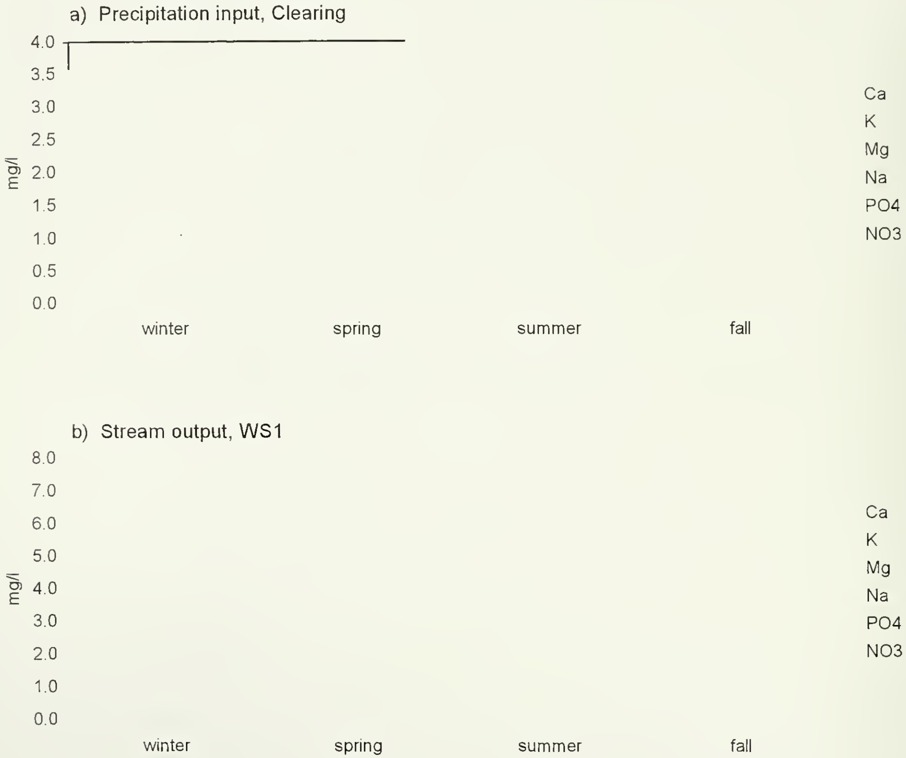
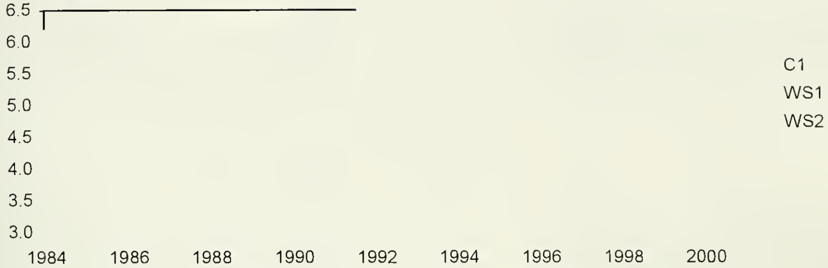


Fig. 5. Comparison of precipitation (C1) and streamwater (WS1, WS2) pH and H^+ ion concentration, 1984-1999.

a) pH



b) H+ concentration

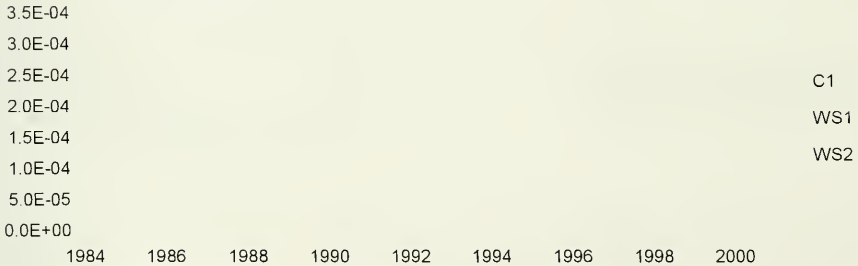


Figure 6. Annual nutrient inputs and outputs (kg/ha) for WS1 and WS2, 1984-1999.

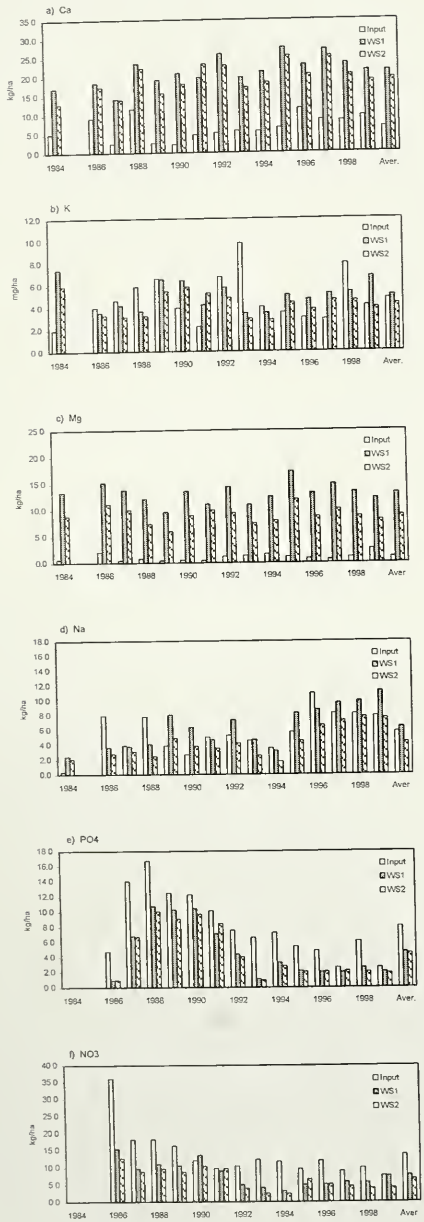


Figure 7 Average monthly nutrient inputs and outputs (kg/ha), WS1 and WS2, 1984-1999

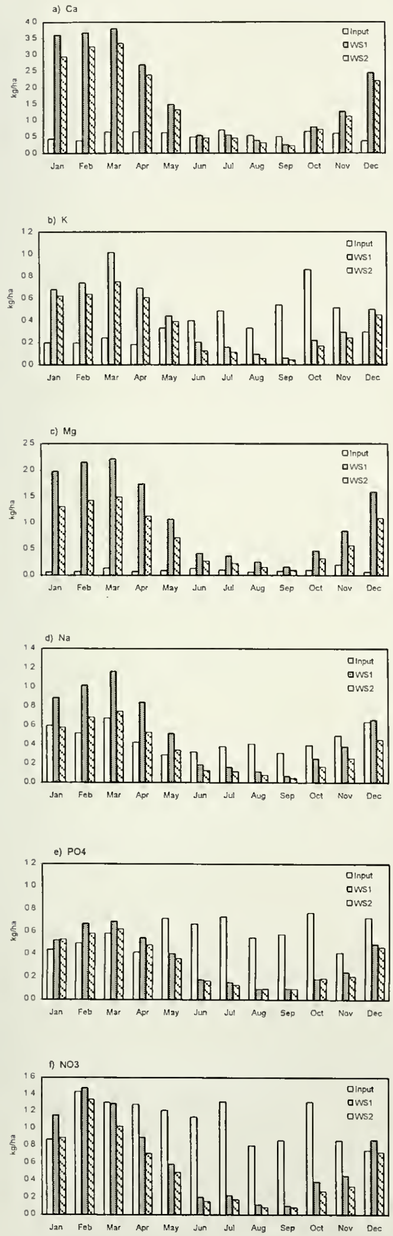
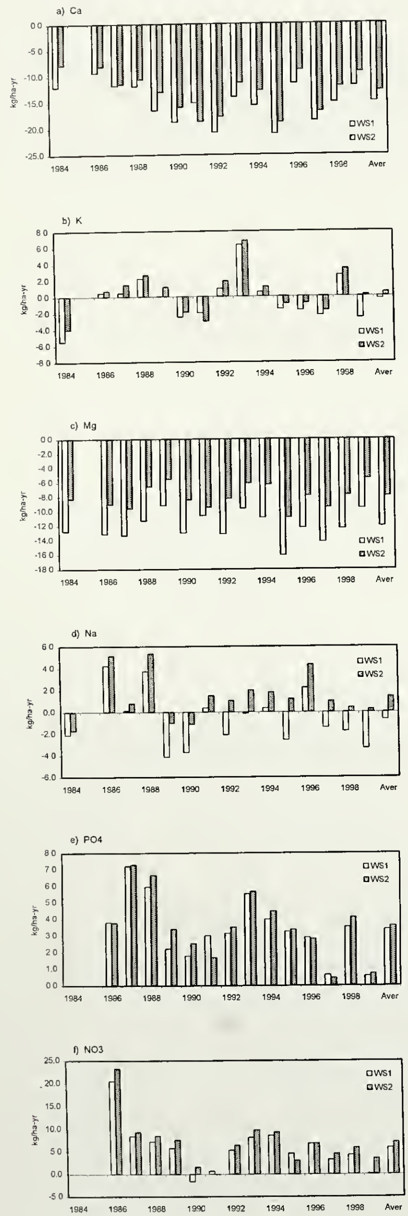


Figure 8. Nutrient budgets for WS1 and WS2, 1984-1999. Positive budgets indicate net accumulation, while negative budgets indicate net loss.



West Virginia University

Davis College of Agriculture, Forestry and Consumer Sciences

WV Agricultural and Forestry Experiment Station
Office of the Dean and Director
1170 Agricultural Sciences
PO Box 6108
Morgantown, WV 26506-6108